Seasonal Dynamics of Pink Bollworm in Cotton Ecosystems of India and Key Ecological Aspects for its Management

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Background

Originating from the Indo-Pakistan region (Saunders, 1843) and co-evolved with cotton (*Gossypium* sp, L.) as its host plant, the pink bollworm (PBW) *Pectinophora gossypiella* (Saunders), (Lepidoptera: Gelechidae), has become a pest of global significance to the cotton growing areas of the tropical and subtropical world (CABI, 2017). Generally, PBW is a late season pest, the infestation of which coincides with the onset of reproductive structures like squaring, flowering and boll development in cotton crop; accounting for colossal yield losses. The larvae of PBW feed on developing flowers buds and the seeds of green bolls of cotton plants, which causes rosetted damaged flowers; premature opening and heavy shedding of infested bolls; reduction in fibre length; and poor quality of lint due to staining (Singh et al., 1988). Being native to India, PBW had adapted to the wider climatic conditions of the country and is able to successfully complete its life cycle between 20°C and 35°C, with the optimal development temperature range between 25°C and 30°C (Peddu et al., 2020). The life cycle of PBW varies with prevailing temperatures and other environmental conditions during cotton growing season, being shortest (35-37 days) during the relatively warmer months of July to October, and longest (59-73 days) during the cooler winter months of November to January (Fand et al., 2021). During the post-cotton season (February to June), PBW larvae hibernate in leftover bolls on cotton stalks that are either standing in the field and or stacked on field bunds, and also in the infested seeds of cotton lint carried to the market yards and ginneries (Mallah et al., 2000; Kranthi, 2015).

Appearances of adult moths *vis-à-vis* commencement of reproductive phenophases of cotton are the two prerequisites critical to the successful field infestation of PBW. Given that these conditions are met, generally it takes about two weeks (14-16 days) from the date of beginning of moth emergence to manifestation of field symptoms of PBW damage in terms of rosette flowers and/ or green boll infestation (Fand et al., 2021) The sequence of events occurring between the moth emergence and manifestation of the symptoms of PBW damage in cotton field are depicted in Figure 1. Because of its cryptic habitat (entire larval development is completed inside the bolls) ensuring protection from insecticidal applications and natural enemies, PBW establishes and perpetuates more easily compared to other insect pests (Kranthi, 2015; Fand et al., 2019). Thus, once the larvae enter the bolls, exogenous insecticide applications often become futile resulting in control failures. Considering the preoviposition period of 2-3 days after moth emergence and the egg incubation period of 4-5 days, altogether, a very narrow window of 7-8 days is available for coincidence of the management actions with oviposition and egg hatching in PBW, with a pre-requisite that the timing of moth emergence is known. The population dynamics and critical biological events in the life cycle of PBW — such as moth emergence, oviposition, egg hatching and larval development — are contingent mainly upon the crop microclimate (temperature, relative humidity and soil moisture) and crop phenology (onset of squares, flowers and green bolls). In view of recent re-emergence of PBW due to resistance development against *Bacilus thuringiensis* (Bt) cotton, and its serious threat to cotton cultivation in India, understanding its seasonal dynamics is crucial in devising ecologically safer and economically sound pest management programmes for this notorious insect pest.

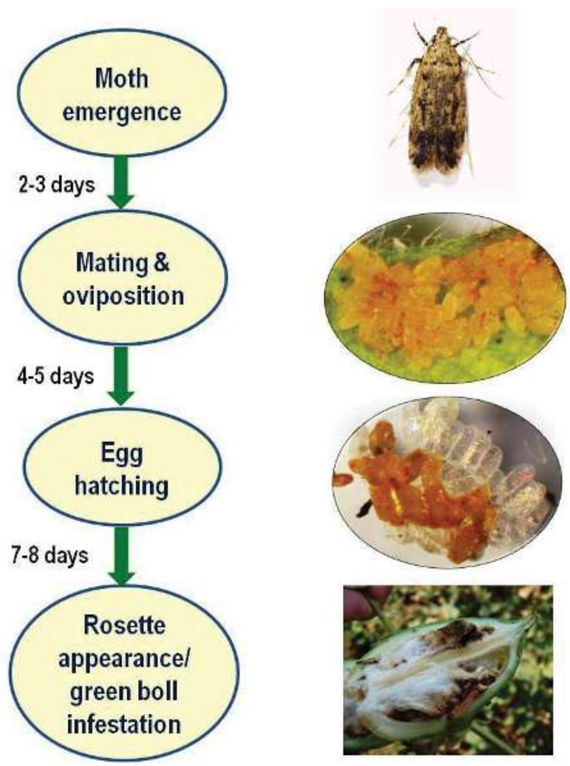

Figure 1. Sequence of events between moth emergence and manifestation of symptoms of PBW damage in cotton field (Adopted from Fand et al., 2021. *Scientific Reports,* 11(436).

Seasonal dynamics of PBW in cotton

Seasonal dynamics of PBW infestation *vis-a-vis* cotton phenology recorded during cotton growing season of 2019-20 using non-Bt cotton cultivar Suraj grown at experimental field of ICAR-CICR, Nagpur (India) is presented here as an example (Figure 2). The crop was completely unprotected from PBW infestation. The moth emergence from previous season's hibernating larvae started in mid-June (data not shown in graph); however it was not consistent as revealed by a very low number and discrete catches of male moths recorded at weekly intervals in pheromone traps installed along the field bunds and internal roads of experimental farm of ICAR-CICR, Nagpur. This irregular flush of moths that continue to emerge until July end to first week of August was supposed to be *suicidal emergence* as the cotton crop sown during the end of June to first week of July did not bear fruiting structures like squares and flowers for the emerging moths to oviposit and initiate the new season's infestation.

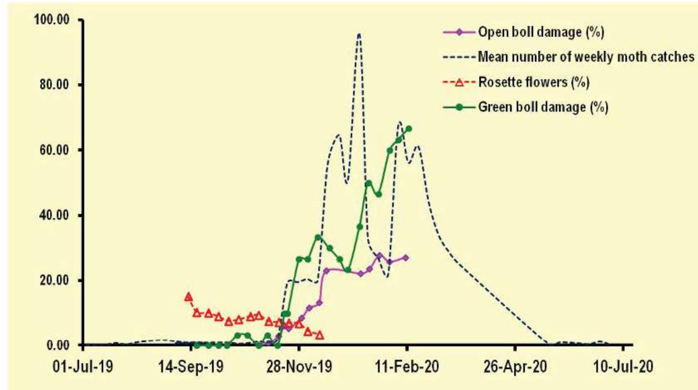

Figure 2. Seasonal dynamics of PBW infestation on cotton crop

Fairly low but consistent moth catches obtained from mid-to-late August seems to have established on the squares and buds giving rise to the rosette flowers from second week of September and subsequently the damage to green bolls from the second week of October. The flower infestation in terms of percentage of rosette was initially above the economic threshold level (ETL) (≥10%) through September, then remained closer to ETL (≤10%) until the end of October and declined steadily thereafter. This may be due to a shift in PBW preference from the squares and flower buds to the green bolls.

Staggered sowing of cotton crop spread over a span of one month due to delayed onset of monsoon at the beginning of season; continuous rains from August to October months resulting in prolongation of the vegetative growth phase; and delay in the flowering and boll formation are the primary reasons for the late beginning of PBW infestation in cotton during the cropping season of 2019/20 compared to earlier seasons (ICAR-CICR, 2020). The PBW infestation in terms of percentage of green boll damage was reasonably below ETL (≤10%) until mid-November, after which it started building up with its first seasonal peak that occurred during mid-December and the two subsequent peaks during mid-January and mid-February. A progressive increase in field infestation with the advancement of the crop season was observed. This was indicated by steep increase toward the end of the season in number of moths captured in pheromone traps and severity of damage to the green bolls and open bolls. For successful development of different life stages of PBW, the lower and upper threshold temperatures of 13.0°C and 34.0 °C and a thermal requirement of 500 ± 5 degree days (DD) are required (Fand et al., 2021). Based on mean DD accumulated between the consecutive moth peaks obtained in sex pheromone traps, it is evident that PBW completed four non-overlapping generations in a cropping season. Considering the intermittent peaks of moth catches, an additional three overlapping generations may be completed by the pest under favourable environmental conditions.

Fitting of linear regression equation (Y = a + bX, where 'Y' is the field infestation of PBW in terms of either rosette flowers, green boll damage or open boll damage; 'X' is the moth trap catch value two weeks prior to appearance of field damage; 'a' is the intercept and 'b' is the slope of regression equation) indicated that the data on mean rosette flowers and mean green boll damage were reasonably related, with the male moth trap catches recorded at two weeks prior to manifestation of damage symptoms in the cotton field. Similarly, the mean open boll damage was linked to corresponding green boll damage recorded two weeks prior to open boll damage (Table 1, Figure 3).

Table 1. Parameters of linear regression equation fitted to estimate the relationship between field symptoms of PBW infestation and moth catches in sex pheromone traps

S.N.	Parameter	Intercept (a)	Slope (b)	df	*F-stat*	*t-stat*	*p*	R^2
1.	Rosette flowers (%) vs moth catches	3.25 (0.95)	7.31 (0.98)	1,6	54.98	7.41	0.001	0.92
2.	Green boll damage (%) vs moth catches	16.44 (3.66)	0.31 (0.08)	1,9	15.01	3.87	0.002	0.67
3.	Open boll damage (%) vs green boll damage (%)	6.98 (2.02)	0.77 (0.14)	1,13	30.04	5.48	0.0001	0.71

*Figures in parentheses are standard errors

Key ecological aspects for devising management strategies for PBW

The squares, flower buds and developing green bolls of cotton plants are the preferred feeding sites for PBW. Normally, the first in-field generation of PBW is completed on squares and flowers, whereas the second generation onwards are completed on green bolls (Ellsworth et al., 2006). The moths emerging from previous season's overwintering population lay eggs on young floral buds (squares). The larvae feed and develop within squares leading to formation of rosette flowers and pupate either in rosette flowers or in soil debris at the base of plant. This sequence of events is repeated for subsequent generations on green bolls instead of squares and flowers (Sevacherian and El-Zik, 1983; Ellsworth et al., 2006). Thus, due to availability of flower buds and bolls, the cotton plant becomes a favourable host for PBW infestation from approximately 40-45 days after sowing (DAS), which usually correspond to late August to mid-September, when the mean environmental temperatures ranges between 24°C to 27°C. The generation developing on squares and flower buds generally takes 35-37 days to complete, by the time the crop will reach 70-80 DAS. With the ample availability of bolls, the second generation develops on green bolls from 80

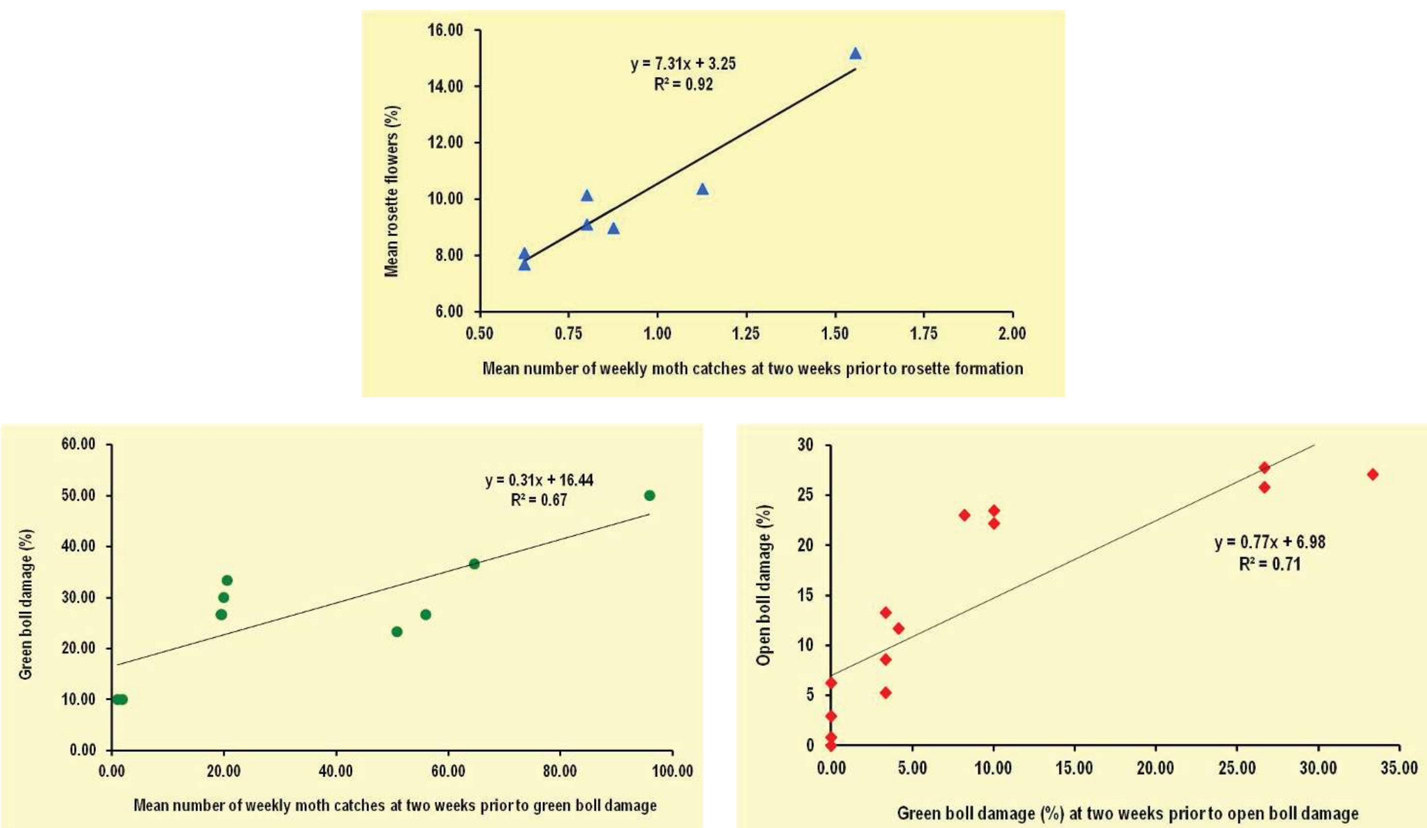

Figure 3. Relationship between field symptoms of PBW infestation and corresponding moth trap catches: rosette flowers (%) vs moth catches (a); green boll damage (%) *vs* moth catches (b); and open boll damage (%) vs green boll damage (%) (c).

to 100 DAS, whereas a third generation occurs when the crop reaches ≥120 DAS. Considering the low survival rate of PBW on squares relative to green bolls, a large population is not expected to build up during early periods of the cotton season. Time-series analysis of data on PBW moth trap catches across different locations of India revealed that the PBW population usually reaches its peak in third generation or later (Fand et al., 2021). This important ecological information is critical to the management of PBW. The management actions oriented toward the monitoring of pest activity (eg installation of pheromone traps) can be initiated during early periods of crop season in order to make timely pest management decisions. The maximum damaging population of PBW during the third generation and onward can be targeted to achieve effective control and to avoid economic yield loss to the cotton crop.

A graph of seasonal dynamics (Figure 2) indicated higher population of PBW built up beginning in mid-December. If the cotton crop is standing in the field for a prolonged duration beyond the normal recommended cropping window, the intensity of boll damage by PBW increases. However, in absence of cotton as its principal host, the population starts diminishing in preparation for overwintering either in the infested bolls of stalks or infested seeds of cotton (Mallah et al., 2000; Kranthi, 2015). Therefore, timely termination of the cotton crop either by the end of December through mid-January has been advocated as one of the important strategies of PBW management in India (Kranthi, 2015). Based on the degree day-based phenology prediction model, Fand et al (2021) have shown that at least two in-field generations of PBW could be prevented and yield losses can be minimised by adopting timely crop termination. The graph (Figure 2) also shows that moth catches started declining after mid-February, however they continued to emerge through April. From May to mid-June there was almost a complete absence of moth emergence. Taking into account the new flush of moths that are expected to emerge from mid-June with onset of monsoon showers, the pre-monsoon sowing (April-May) adopted in few scattered irrigated pockets is not advisable in order to escape the damage from suicidal population of PBW. Timely removal and destruction of infested crop residues to reduce the inoculum load of hibernating pests and monitoring and management of off-season flushes of moths emerging from infested cotton seeds through installation of sex pheromone traps and/ or light traps in the premises of market yards and ginneries are required.

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